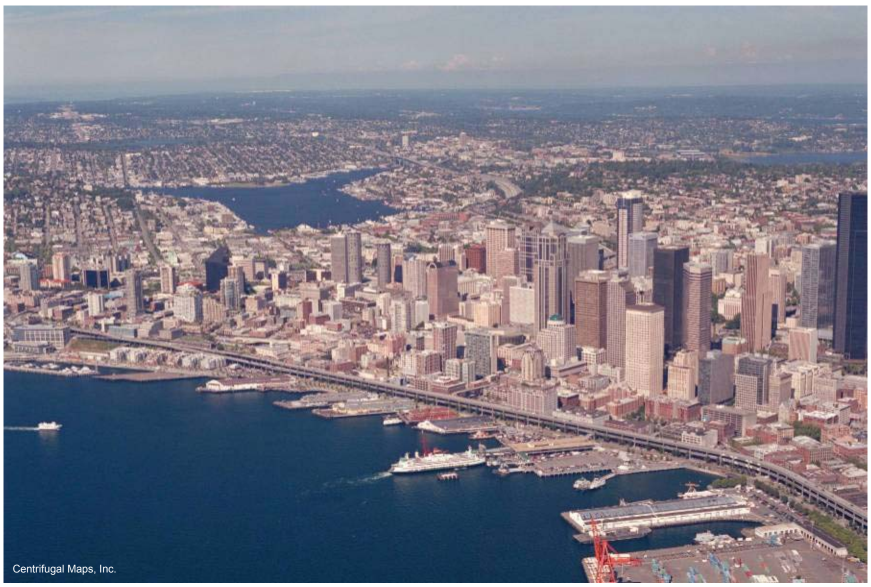
SR 99: ALASKAN WAY VIADUCT & SEAWALL REPLACEMENT PROJECT

Tsunami Risk to Proposed Waterfront Tunnel in Seattle (Draft)



Submitted to:
Washington State Department of Transportation
Urban Corridors Office
401 Second Avenue S, Suite 560
Seattle, WA 98104-3850

Submitted by:
Parsons Brinckerhoff Quade & Douglas, Inc.

Prepared by:
Parsons Brinckerhoff Quade & Douglas, Inc.

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Tsunami Risk to Proposed Waterfront Tunnel in Seattle

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Task 300

The SR 99: Alaskan Way Viaduct & Seawall Replacement Project is a joint effort between the Washington State Department of Transportation (WSDOT), the City of Seattle, and the Federal Highway Administration (FHWA). To conduct this project, WSDOT contracted with:

Parsons Brinckerhoff Quade & Douglas, Inc.
999 Third Avenue, Ste 2200
Seattle, WA 98104

In association with:

BERGER/ABAM Engineers Inc.
BJT Associates
David Evans and Associates, Inc.
Entech Northwest
EnviroIssues, Inc.
Harvey Parker & Associates, Inc.
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Tom Warne and Associates, LLC
William P. Ott

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EXECUTIVE SUMMARY

There has been some concern of the possibility that a tsunami wave could flood the Alaskan Way Viaduct's future tunnel replacement, the Alaskan Way Viaduct project's preferred alternative. Recent research has concluded that there is not a significant risk of this happening.

The tunnel is being designed to withstand earthquake forces so large, that they occur only every 2,500 years, on average. Previous highway facilities were designed to withstand much smaller earthquake forces, which occur more frequently – roughly every 500 years.

Tsunamis, generated by earthquakes of sufficient magnitudes and specific types, are rare events, in and of themselves. Tsunamis that could adversely affect the Seattle waterfront are extremely rare. In fact, in the last 6,000 years, only one tsunami is known to have occurred with waves of sufficient height to overtop the Seattle seawall. To top the Seattle seawall, this tsunami would also have had to occur during the short time that the sea level happened to be at mean high tide or greater.

Taking into account the short timeframe during which the water level would be at or above mean high tide on any given day, we reached the conclusion that a tsunami that could affect a future waterfront tunnel would be so improbable that it could only happen approximately every 60,000 years. This is well beyond the tunnel earthquake design standard and way outside the standard limits applied to civil engineering design. This finding is based on inundation maps produced by the National Oceanic and Atmospheric Administration (NOAA) following computer modeling of maximum credible tsunamis in Puget Sound.

In summary, the review of recent research found:

- The tunnel is being designed to withstand an earthquake that only happens every 2,500 years.

- A tsunami that could affect the tunnel would likely occur only once approximately every 60,000 years.

- The tunnel will be a safe and secure facility designed to the highest standards ever applied to a highway facility in the state of Washington.

Based on the facts and research presented in this paper it is recommended that the tunnel design continue as planned without taking any additional tsunami-related measures.

BACKGROUND

Planning and conceptual design studies for the replacement of the earthquake damaged Alaskan Way Viaduct and Seawall began in August of 2001. On December 6, 2004, the Washington State Department of Transportation and the City of Seattle jointly announced that the preferred alternative along the waterfront was a tunnel. A few weeks after this announcement (December 26, 2004), a tsunami generated by a massive earthquake in the Indian Ocean caused widespread destruction and loss of life. An estimated 176,000 people in 11 countries were killed, with about 50,000 more missing and hundreds of thousands left homeless. Concern was raised regarding the possibility that the new tunnel under consideration could be flooded by a tsunami generated either off the coast of Washington or within Puget Sound. An investigation was made to determine the causes, likelihood, and effects of such a tsunami. The findings of the investigation are documented in this paper.

TSUNAMIS

What is a Tsunami? While the word means "great wave" in Japanese, a tsunami is really a series of traveling ocean waves of extremely long length that result from a large disturbance in the ocean floor topography. Heaving of the seabed due to a very large earthquake, underwater volcanic eruptions and landslides can generate tsunami waves. In the deep ocean the length of the wave, measured from crest to crest, may be a hundred miles or more but the wave height will be a few feet or less. The waves are typically not felt by ships on the open ocean and cannot be seen from the air. These open ocean deep water waves may reach speeds exceeding 500 miles an hour. As the wave approaches the shoreline the wave's height increases, with heights up to 100 feet recorded. The same is not true for tsunami waves generated within a small basin such as Elliott Bay or Puget Sound where wave velocity and height upon reaching shore would be much less.

The tsunami produced by the recent magnitude 9.1 earthquake in the Indian Ocean caused a series of waves that reached heights up to 50 feet as they came ashore and are thought to have traveled at speeds up to 450 miles per hour in the open ocean. While this was an extremely rare event, it gives rise to concern that a similar event could take place near Seattle. In order to understand the tsunami risk to Seattle, tsunami sources capable of generating the highest waves in Puget Sound must be understood.

All earthquakes do not cause tsunamis; in fact, most earthquakes do not. The recent Nisqually earthquake that struck the region on February 28, 2001, at a magnitude of a 6.8, did not cause a tsunami. There needs to be a sharp vertical movement of the ocean floor in order to cause a tsunami. Earthquakes occurring deep underground (e.g., greater than 30 miles like the Nisqually Earthquake) or causing movement in a horizontal direction below the surface do not cause tsunamis. The massive aftershock (magnitude 8.7) that struck the Indian Ocean off the coast of Sumatra on March 28, 2005, in the same area that the massive tsunami was generated on December 26, 2004 caused only a minor tsunami because the movement of the sea floor was more horizontal and much less vertical.

NORTHWEST EARTHQUAKE MECHANISMS

There are two seismic sources that have been identified as capable of producing the tsunamis that could affect the Seattle shoreline. The first is the Cascadia Subduction Zone which is a joint between two major tectonic plates of the earth's crust that extends along the coast from Vancouver Island to northern California. The second is the recently discovered Seattle Fault that runs approximately east-west from east of Lake Sammamish to the Kitsap Peninsula.

Cascadia Subduction Zone

Mega-thrust earthquakes along the Cascadia Subduction Zone (magnitude 8 to 9) are thought to have occurred about every 400 to 600 years. The last major earthquake is thought to have occurred in January, 1700. Based on the size of the tsunamis that hit Japan, it has been estimated to have been a magnitude 9.0 event.

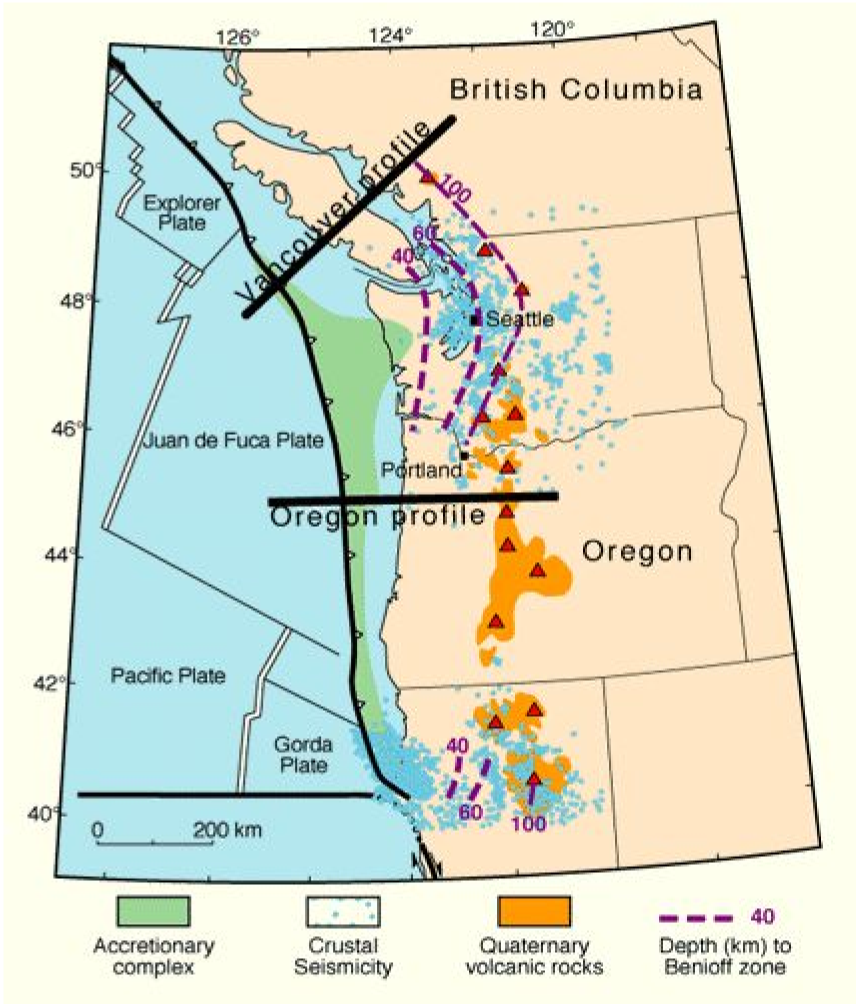

Figure 1: Cascadia Subduction Zone

Seattle Fault

Large seismic events along the Seattle Fault Zone (magnitude 7) are thought to occur at intervals of about 2,000 to 6,000 years. The most recent large earthquake on the Seattle Fault occurred approximately 1,100 years ago and produced a tsunami that traveled north and south in Puget Sound. Research has traced back seismic activity on the Seattle Fault 6000 years with no evidence of a tsunami besides the one in 930 A.D.

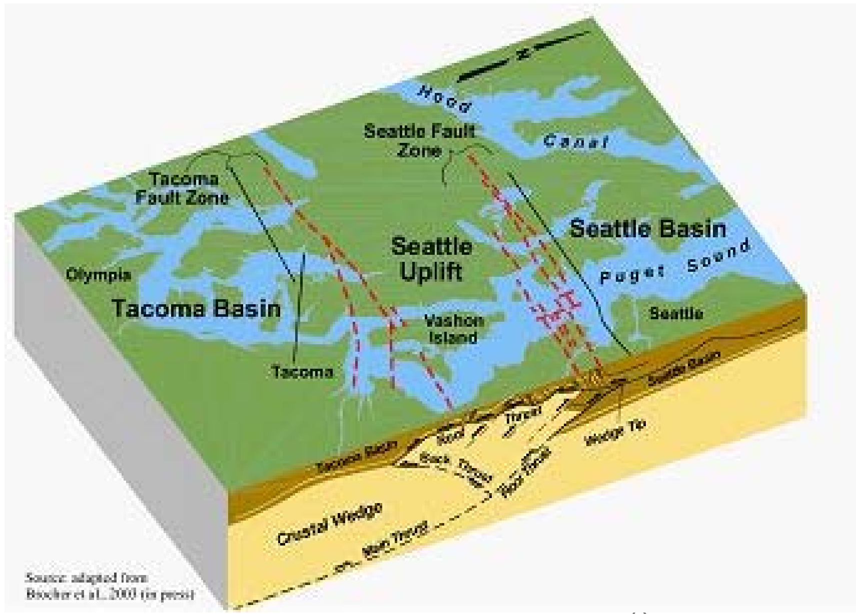

Figure 2: Seattle Fault

RECENT RESEARCH

The Seattle Fault has been the subject of a significant amount of research since its discovery in 1965 by Danes and others. Geologic evidence at Alki Point in West Seattle and at Restoration Point south of Port Blakely Harbor on Bainbridge Island reveal that an earthquake in approximately 930 A.D. caused a vertical uplift of 21 feet on Bainbridge Island and 16 feet in West Seattle, with a corresponding downward movement of land masses north of West Point. The seabed uplift between Bainbridge Island and West Seattle is thought to have caused the only known tsunami generated along the Seattle Fault. Geologic evidence suggests that two to three other significant earthquakes may have occurred in the 1500 years previous to the 930 A.D. event. However, no evidence has been found that indicates these earlier events caused a significant uplift in the seabed or produced significant tsunamis.

The National Tsunami Mitigation Program was established by the Federal Government in October of 1996. In 2003, NOAA in conjunction with the Washington State Department of Natural Resources, sponsored specialized computer modeling to produce inundation maps. They used numerical computer modeling to reproduce the 930 A.D. earthquake that occurred on the Seattle Fault to predict the extent of flooding due to tsunami waves. They produced maps to guide in selecting evacuation routes in the event that a similar major earthquake on the Seattle Fault produces a similar tsunami. This work was done by Titov and others using a fine meshed finite difference computer program to simulate the 930 A.D. tsunami. The results of the computer modeling indicate that a series of waves approximately 16 feet high would result in a 10 foot high storm surge along the shoreline of Seattle. The height of the 930 A.D, event tsunami waves has generally been validated by fieldwork in trenches and excavations along the Puget Sound shoreline that measured depth of debris deposited by tsunami waves. It is estimated that tsunami waves from the 930 A.D. earthquake took less than 5 minutes to reach the Seattle shoreline after the earthquake.

NOAA computer modeling predicted that tsunami waves, produced by the January, 1700 earthquake on the Cascadia Subduction Zone, traveled from the open ocean where they were generated, into the Strait of Juan de Fuca, turned right and traveled south in Puget Sound and finally turned east into Elliott Bay before striking the shoreline of present day downtown Seattle with an approximate storm surge height of 5 feet. Based on similar fieldwork as that done for the Seattle Fault tsunami, the height of the waves for this event was also confirmed. The NOAA models predict that it would take approximately 2.5 hours from the time an extreme earthquake took place on the Cascadia Subduction Zone until the waves struck the Seattle Shoreline.

The NOAA inundation maps represent the best current scientific means to estimate the flooding produced by tsunamis generated either off the coast of Washington or in Puget Sound. The nature of the tsunami waves depends on the initial deformation of the sea floor and, because this is still poorly understood, the predictions of the modeling shown on the inundation maps may contain significant errors. The data represents the best available science, but experts acknowledge there is still much to learn about earthquakes and tsunamis. Because they were produced as the basis for evacuation planning they are thought by many to be very conservative.

BASIS FOR DESIGN

The elevation of the Alaskan Way surface roadway along the waterfront in Seattle is approximately 17 feet above sea level. The elevation of mean high water (i.e. high tide) is approximately 8 feet above sea level, leaving 9 feet of protection during high tides. Based on available modeling and geologic evidence, tsunamis generated by seismic events on the Seattle Fault would result in a 10 foot high storm surge or flood above the water level at the time of the event that would come ashore in Seattle. Since the seismic events causing these tsunamis are maximum credible events for this location, the resulting 10 foot high flood also represents the maximum height of water that could be generated by a tsunami in Elliott Bay..

Since the sum of the expected 5 foot tsunami storm surge height plus the mean high tide height of 8 feet is less than the 17 foot seawall elevation, no water from a Cascadia Subduction Zone event is expected to reach the tunnel. Further analysis of such an event is therefore not warranted.

With the Seattle Fault tsunami remaining as the only risk of producing a flood that could overtop the seawall, the nature of this risk requires further study. The Seattle Fault tsunami flood is only capable of overtopping the seawall if the level of the water in Elliott Bay is at mean high tide or greater. A statistical analysis of the water level of Elliott Bay recorded by NOAA for the previous 50 years was undertaken. It was found that the percentage of the time the water is at mean high tide or greater varies from about 10% to 13% of the time, depending on the year.

PROBABILITY OF TSUNAMI IMPACTS

As previously stated, research has found evidence of only one tsunami generated by a seismic event on the Seattle Fault in the past 6,000 years. It can be conservatively assumed that a maximum size tsunami could be produced on a recurrence period of 3,000 to 6,000 years. But in order for this tsunami to overtop the seawall, it would have to occur during the time that the water level in Elliott Bay was at mean high tide or greater. Since this only occurs 10-13% of the time, and the events are unrelated, the resulting recurrence period for a maximum tsunami generated flood is in the range of 23,000 years to 60,000 years. This places the risk of a tsunami flood along side that of a large meteor striking the earth.

CONCLUSION AND RECOMMENDATION

It would take an extremely rare event to cause a tsunami with sufficient storm surge wave action to enter the recommended tunnel replacement of the Alaskan Way Viaduct. The probability of such an event is far less than the tunnel's design earthquake probability and outside the range of practice for major public civil engineering projects.

Since the new tunnel will be designed as one of the most earthquake-resistant structures ever built in Seattle, it will be the preferred waterfront location in the event of a major seismic event. Based on the facts and research presented in this paper it is recommended that the tunnel design continue as planned without taking any additional tsunami-related measures.

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